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MEMORANDUM

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FROM:	Harriet Phillips	31 March 2010
SUBJ:	Re-evaluation of the Giant Mine Human Health and Ecological Risk Assessment	

This memorandum documents the results of our review of the inputs and assumptions that went into the Giant Mine risk assessment dated January 2006 (SENES 2006) to determine whether the overall conclusions made in that assessment are still valid. The following paragraphs provide the basis for our conclusion that the findings from the risk assessment completed in 2006 remain unchanged.

1. Inputs and Assumptions to 2006 Risk Assessment

Measured data up to 2004 were used for water, sediments, fish, small mammals, berries, soil, terrestrial vegetation, medicinal plants. There have been some data collected since 2004 and these data are discussed below.

i) Water Quality

For assessment purposes, Yellowknife Bay was subdivided into three segments comprising Back Bay, North Yellowknife Bay and South Yellowknife Bay as shown in Figure 1. Table 1 provides summary statistics on the measured arsenic concentrations in these segments in each of the past four decades.

The data show that the arsenic concentrations were highest in the 1970's and have declined over time as a result of reduced load inputs to the receiving environment. Limited sampling in the 2000's indicates that the geometric mean concentration in Back Bay and North Yellowknife Bay was approximately 0.4 µg/L. Lake dispersion modelling undertaken in support of the risk assessment predicted mean arsenic concentrations in the 1990 to 2010 period in the range of 2.8 to 3.5 µg/L in Back Bay and 1.3 to 1.6 µg/L in North Yellowknife Bay. Overall, the predicted concentrations agree reasonably well with the measured levels (i.e. the predicted levels fall within the range of measurements over this period) although predicted levels are higher than measured in the most recent ten-year period. This comparison suggests that the use of the predicted concentrations in the risk assessment would tend to over-state potential risks in the aquatic environment. As there is no new information that would cause us to update the lake dispersion modelling, it is concluded that this component of the risk assessment stands as presented in the 2006 RA.

Table 1 Changes in Arsenic Concentrations in Yellowknife Bay Over Time (µg/L)

	Number of Samples	Geometric Mean	Range	
			Minimum	Maximum
Back Bay				
1970's	14	31	1.0	740
1980's	5	7.0	6.0	8.0
1990's	30	1.8	0.3	8.6
2000's	5	0.4	0.4	0.5
North Yellowknife Bay				
1970's	5	24	4.0	83
1980's	3	2.8	0.6	7.4
1990's	18	2.5	0.3	6.9
2000's	3	0.4	0.4	0.4
South Yellowknife Bay				
1970's	1	530	-	-
1980's	6	1.0	1.0	1.0
1990's	28	1.2	0.3	14
2000's	-	-	-	-

ii) Fish Concentrations

Measured concentrations in fish were obtained for studies up to 2001 and are summarized in Appendix A of the 2006 Risk Assessment (SENES 2006). Measured concentrations in Lake Whitefish ranged from <0.05 to 1.11 mg/kg wet weight (ww), in Northern Pike from 0.03 to 0.8 mg/kg ww and in Longnose Sucker from 0.21 to 0.32 mg/kg ww. In 2004, de Rosemond *et al.* carried out studies on arsenic levels in fish obtained from Back Bay. Measured arsenic concentrations in the muscle of Lake Whitefish, Northern Pike and Longnose Sucker were 0.77 mg/kg dw (0.15 mg/kg ww), 0.97 mg/kg dw (0.2 mg/kg ww) and 1.1 mg/kg dw (0.23 mg/kg dw) respectively. The data presented by de Rosemond *et al.* (2004) were considered in the risk assessment as indicated in Appendix A5.0 of the 2006 Risk Assessment and were found to be quite similar to concentrations from earlier studies into arsenic levels in fish caught in Yellowknife Bay. The measured levels were used to estimate transfer factors for use in pathways model predictions of arsenic levels in fish in the future. The basis used in the 2006 RA for estimating risks to fish species and exposure levels for wildlife and people who consume fish are considered to be reasonable and do not need to be revisited.

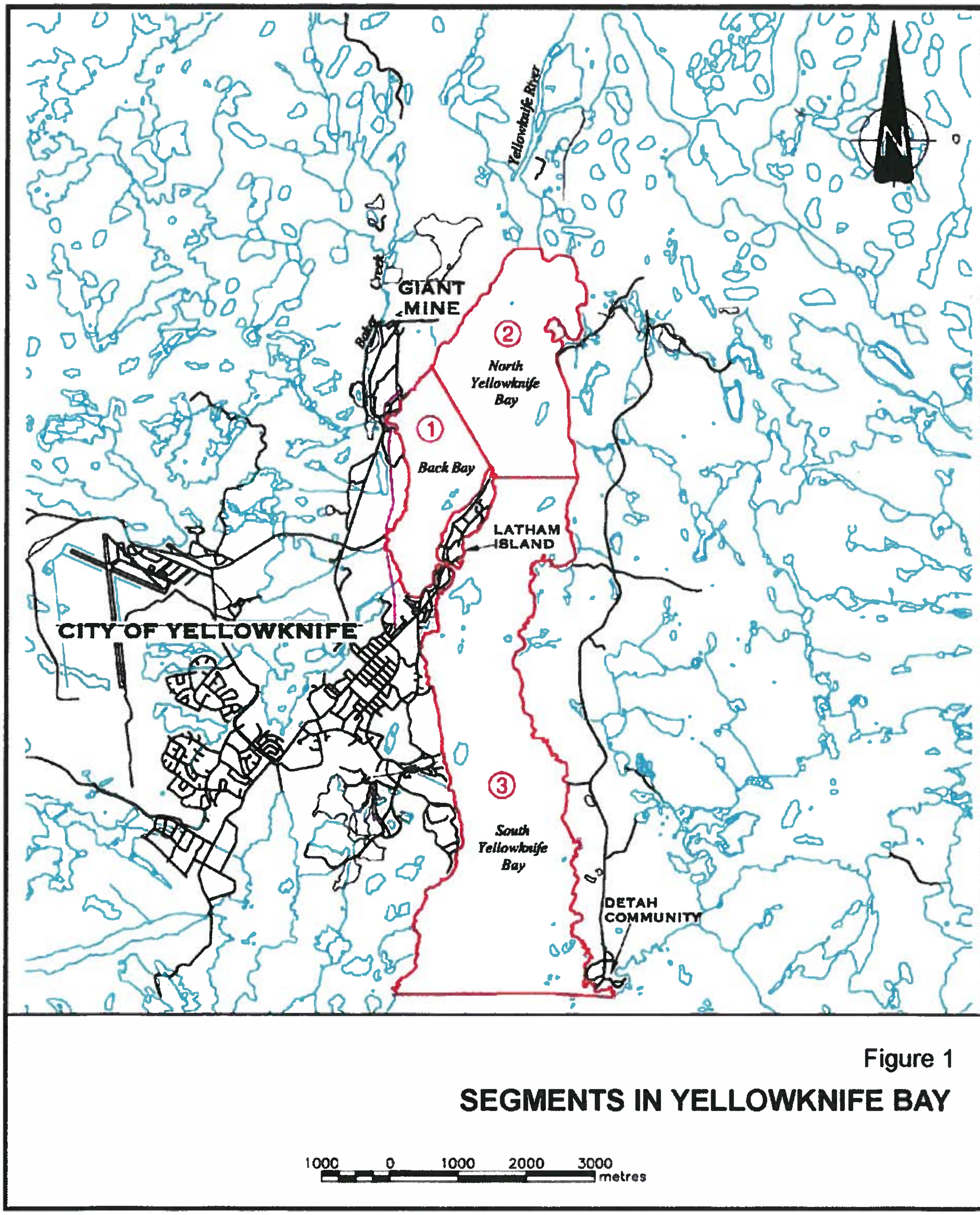


Figure 1
SEGMENTS IN YELLOWKNIFE BAY

iii) Avian Concentrations

Bird concentrations were predicted in the 2006 risk assessment report using literature transfer factors. Koch *et al.* (2004) measured arsenic concentrations in terrestrial birds in the Yellowknife study area. The predicted concentration in grouse tissue as presented in Appendix D was 0.58 mg/kg ww (1.9 mg/kg dw). Measured bird concentrations in the breast of avian species in the Yellowknife area ranged from 1.1 to 8.6 mg/kg dw with the spruce grouse reporting the lowest concentration and the tree sparrow having the highest concentration. Concentrations in Dark-eyed junco, Yellow-rumped warbler and Gray jay were 2.7, 3.0 and 3.6 mg/kg dw respectively. It should be noted that the majority of the arsenic was in the form or arsenobetaine (non-toxic form of arsenic) whereas the risk assessment assumed that all the arsenic was in the toxic inorganic form. Thus the modelled data provides a reasonable estimate of the avian concentrations that are reported and the risk assessment used the cautious assumption that all the arsenic was in a toxic form.

iv) Modelling – Sediment Transfer

Sediment arsenic concentrations at the outlet of Baker Creek, in Back Bay and in Yellowknife Bay were investigated on several occasions. Arsenic concentrations in sediments at Baker Creek Outlet over the 1992 to 1997 period ranged from 1337 mg/kg dw to 2838 mg/kg dw. In 2001, the sediment concentrations ranged from 1270 mg/kg dw to 2270 mg/kg dw. In 2002, the sediment arsenic concentrations ranged from 124 mg/kg dw to 1710 mg/kg dw and in 2004 from 615 mg/kg dw to 2350 mg/kg dw. These results are presented in Appendix B of the 2006 RA document.

In 2006, Andrade reported on arsenic concentrations measured in sediment samples collected from the outlet of Baker Creek in 2003 and 2004. These results are summarized in Table 2. Two sediment samples were collected at the vicinity of the Baker Creek breakwater, two samples in Yellowknife Bay, and one sample each in Back Bay and Akaitcho Bay (Southeast region of Yellowknife Bay). The arsenic concentrations reported in Table 2 for Baker Creek outlet sediments are similar to those measured in previous studies. It is significant to note, that the concentration was substantially less in the top 0 to 2 cm than deeper into the sediments indicating gradual improvement.

Typically, sediments from Yellowknife Bay show two concentration peaks. As shown in Table 2, the Northern section of Yellowknife Bay has high surface (0 to 0.75 cm) arsenic levels of 530 to 1080 mg/kg dw with a secondary peak of 1020 to 1300 mg/kg dw at the depth of 7.5 to 8.5 cm. The estimated composite average concentration of 252 to 288 mg/kg dw for 0 to 5 cm depth was similar to the values reported by HydroQual (1989), Mudroch *et al.* (1989), and Jackson *et al.,* (1996) presented in Appendix B of the 2006 RA.

The results of the model simulations from the 2006 RA (SENES 2006) were compared with measured sediment concentrations derived from the observations of Andrade (2006). Model predictions were for a depth of 0 to 5 cm, which is regarded as the active water column-sediment exchange zone. Sediment concentrations were predicted from the start of operations in the 1950's to capture historic releases to the atmospheric and aquatic environments. Arsenic levels in the lake sediments were predicted to peak in the 1970's and decline slowly afterwards. The measured peak concentrations at depths of 7.5 to 8.5 cm into the sediments (Andrade 2006) are consistent with the predictions.

Table 2 Arsenic Concentrations In Yellowknife Bay, Back Bay and Baker Creek Sediments Based on Andrade (2006)

Depth (cm)	Arsenic Concentration in Sediments (mg/kg dw)					
	Yellowknife Bay			Back Bay	Baker Creek Outlet	
	Between Baker Ck Outlet and Latham Island (2003)	Between Baker Ck Outlet and Latham Island (2004)	Akaitcho Bay South of Dettah	Opposite South End of Latham Island	Inside the Break Water (2003)	Outside the Break Water (2004)
0.25	601.7	1083.6	47	228.9	1344.4	1304.7
0.75	656.9	530.1	72.3	236.6	1163.5	1691.1
1.25	114	196	44.5	239.7	821.9	2718.3
1.75	70.2	150.4	15	256.3	858.9	3525.9
2.25	62.5	112.9	25.6	288	1103.9	2421.5
2.75	70.7	97.2	12.3	325	1197.8	1585.1
3.25	97.2	107.6	11.7	183.2	1328.6	1107.1
3.75	118.1	113.3	12.1	84.5	933.5	2056.2
4.25	142.8	114.6	13	79	1549.8	5886.2
4.75	369.8	151.3	12.3	116.3	2659.1	889.3
5.5	584	443.1	12.4	147.9	3316.8	1235.7
6.5	987.3	952.6	13.6	118.4	4674.3	1101.6
7.5	1017.4	1232.3	15.5	83.7	5293.8	2337.4
8.5	1309.9	1043.3	18.2	31.2	3784.4	1925.1
9.5	937.7	671.6	20.6	22.3	2076.2	5104.2
10.5	911	661.1	24.2	19.4	191.6	6258.4

The predicted arsenic concentrations from the 2006 RA (mean and range of 5^{th} to 95^{th} percentile) are compared with measurements taken by Andrade (2006) and the principal observations used for model calibration (HydroQual, 1989) in Table 3. In addition, data from Dillon (2002) on Back Bay sediments are also used for comparative purposes. The observations calculated from data taken by Andrade (2006) are the composite average concentration of samples taken over two years over the 0 to 5.5 cm depth.

Using the data of Andrade (2006), the 95% confidence intervals of the measured mean values were calculated. For Yellowknife Bay, the 95% confidence interval range on the mean is 160 to 384 mg/kg while for Baker Creek the 95% confidence interval range on the mean is 1376 to 3082 mg/kg.

As seen from the table, model predictions are well within the statistical confidence interval of the observed values from Andrade (2006). It is seen that the predicted sediment concentrations agree reasonably well with the measured levels in Yellowknife Bay as well as at the outlet of Baker Creek. Based on these comparisons, it is concluded that the results of the 2006 RA are still valid.

Table 3 Comparison of Model Predicted Arsenic Concentrations With Measurements

Source	Sediment Arsenic Concentrations (mg/kg dw)			
	North Yellowknife Bay		Baker Creek Outlet	
	Mean	Range	Mean	Range
Model Prediction (2006 RA)	175	165 to 190[1]	2250	2,185 to 2,425
Andrade (2006)	270	160 to 384[2]	1972	1,376 to 3,082
HydroQual (1989)	197	13 to 1000[3]		-
Dillon (2002)	-		1887	1270 to 2270[3]

Note: [1] represented by the 5th and 95th percentile of the model predictions.
[2] represented by the 95% confidence level on the mean.
[3] represented by the minimum and maximum of the measured data.

v) TRVs – Ecological

In the 2006 RA both $EC_{20/25}$ and EC_{10} values were used as aquatic TRVs. The results indicated that there would be no risks to aquatic species in Back Bay, North Yellowknife Bay and South Yellowknife Bay using either TRV; however, there would be some potential risks to predator fish and forage fish in Baker Creek using EC_{10} TRVs.

Since the time of the assessment, a review of arsenic TRVs reported in refereed sources has been undertaken and a comparison of the TRVs is provided in Table 4. As seen from the table, the TRVs for aquatic plants and benthic invertebrates have decreased whereas the TRV for predator fish has increased. The change in the TRVs does not change the results related to EC_{10} and EC_{20} TRVs in aquatic species in Back Bay, North Yellowknife Bay and South Yellowknife Bay. The overall conclusions in Baker Creek that indicate potential effects in aquatic species will also remain unchanged.

Table 4 Summary of Toxicity Reference Values for Aquatic Species

Aquatic Receptor	Arsenic (mg/L)			
	Toxicity Reference Value $EC_{20/25}$ (2006)	Toxicity Reference Value EC_{10} (2006)	Updated EC_{20} TRVs	Updated EC_{10} TRVs
Aquatic Plants	0.32	0.16	0.25	0.12
Benthic Invertebrates	0.34	0.17	0.12	0.06
Predator Fish	0.14	0.07	0.63	0.32
Bottom Feeder Fish	0.12	0.06	0.12	0.06

Sediment toxicity benchmarks were taken from a variety of sources including Northern Canada and remain unchanged. The risk assessment indicated that there are potential adverse effects on benthic organisms in Baker Creek. This is supported by sediment toxicity tests by Jacques Whitford (2005) which indicated that sediments in Baker Creek "*pose a significant threat to benthic organisms.*"

A review of the arsenic TRVs for terrestrial animals and birds was also undertaken using information provided in the U.S. EPA Ecological Soil Screening Levels (Eco SSLs - 2005). TRVs for growth and reproduction were determined for different species and a comparison of the TRVs is presented in Table 5. As seen from the table, the lowest observed adverse effect level (LOAEL) TRVs related for growth and reproduction from the Eco SSL data for terrestrial mammals are higher than the TRVs that were used in the 2006 RA. For the avian species, the LOAEL TRVs for growth and reproduction for avian species are similar to the no observed adverse effect level (NOAEL) TRVs that were used in the 2006 RA (SENES 2006).

Table 6 provides the appropriate TRVs for arsenic corresponding to the terrestrial receptors that were used in the risk assessment. The use of the TRVs for mammals from the Eco SSL document which are presented in Table 6 results in no risks for muskrat and hare (risks were indicated in the 2006 RA). For the mink, risks are now only identified for the 95^{th} percentile exposure (risks were indicated at both mean and 95^{th} percentile exposures in the 2006 RA document). The results for caribou, bear, moose and wolf remain unchanged with the updated TRVs (i.e. no risk identified). In conclusion, the 2006 RA overestimates risks and therefore represents a cautious approach.

The updated TRVs for ducks, which are for growth and reproductive endpoints, are similar to the NOAEL TRVs that were used in the 2006 RA. The results showed that predicted exposures were below this NOAEL TRV and therefore the results remain unchanged. For grouse, the TRV is below the NOAEL value of 5.1 mg/(kg d) that was used in the 2006 RA; however, the predicted exposures are well below a TRV of 3.6 mg/(kg d) and therefore the results would remain unchanged. In summary, a change in the TRVs for avian species does not result in any changes from the 2006 RA (SENES 2006).

Table 5 Comparison of Toxicological Reference Values for Arsenic Based on Laboratory Animal and Bird Studies

	Small Mammals (muskrat, mink, hare)	**Large Mammals (wolf, bear)**	**Large Mammals (moose, caribou)**	**Birds**
Source of Reference Values	Sample *et al.* (1996)	ATSDR (2000)	Puls (1994)	Sample *et al.* (1996)
Original Reference	Schroeder & Mitchener (1971)	Byron *et al.* (1967)	-	USFWS 1964
Form of chemical	Arsenite (As^{3+})	Arsenite (As^{3+})	Arsenic Trioxide	Arsenite (As^{3+})
Test Species	Mouse	Beagle Dog	Cattle	Mallard duck
NOAEL (mg/kg d) – 2006 RA	**-**	**1.0**	**-**	**5.15**
LOAEL (mg/kg d) – 2006 RA	**1.26**	**2.4**	**1.1**	**12.84**
Updated LOAEL TRVs from Eco SSL 2005 document	**14.2 (Rat) 20.7 (Mouse) 3 (Rabbit)**	**3.1 (Dog)**	**14.1(Goat)**	**5.1 (Mallard) 3.6 (Chicken)**

Table 6 Summary of Arsenic Toxicological Reference Values for Terrestrial Species

COPC		**Species**	**LOAEL -2006 Risk Assessment (mg/(kg d))**	**Updated LOAEL Based on 2005 EcoSSL Document (mg/(kg d))**
Arsenic	Birds	Duck	12.84	5.1
		Grouse	12.84	3.6
	Mammals	Bear	1.15	3.1
		Caribou	1.62	14.1
		Hare	0.48	3
		Mink	0.52	3.1
		Moose	1.05	14.1
		Muskrat	0.5	14.2
		Wolf	1.74	3.1

vi) TRVs – Human

The 2006 risk assessment report used a TRV that was derived by Health Canada (2004) in their proposed drinking water study. This TRV was derived from a study by Morales *et al.* (2000) and was based on liver, lung, bladder and kidney cancers. An oral slope factor of 1.2 $(mg/(kg\ d))^{-1}$ was determined from this data. A sensitivity analysis was also conducted using an oral slope factor of 2.8 $(mg/(kg\ d))^{-1}$ which was based on skin cancers.

Health Canada (2009) has developed an oral slope factor of 1.8 $(mg/(kg\ d))^{-1}$ which is based on the same study by Morales *et al.* (2000) related to bladder, lung, and liver cancer. This value falls between the two slope factors that were used to evaluate the risks from arsenic exposure in the 2006 risk assessment. Thus the overall conclusions of the 2006 risk assessment are still valid since the total lifetime risks (which include background) are within the range of risk levels associated with typical exposures of the general Canadian population.

vii) Exposure Calculations – Bioavailability

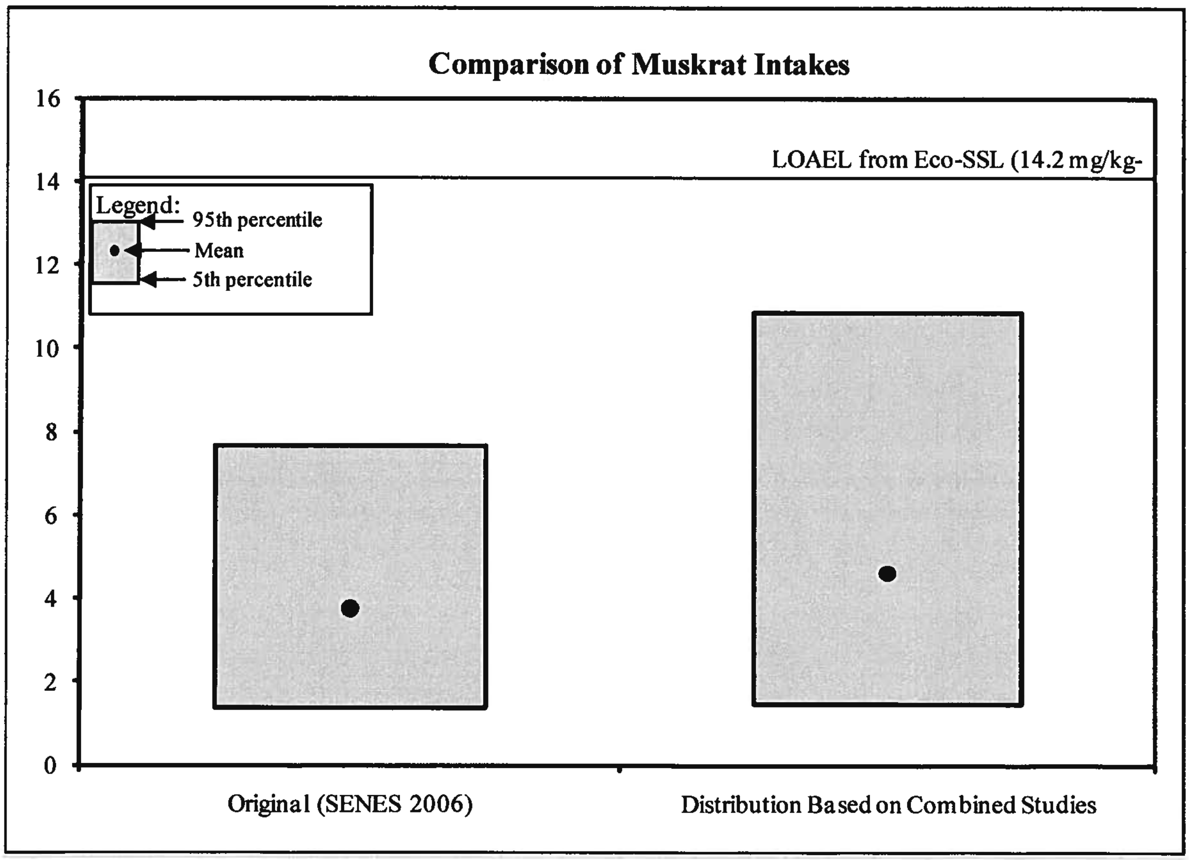
Sediment samples were collected from 7 locations in Baker Creek in 2004 and these samples were subjected to various analyses including sequential extraction and bioaccessibility tests. The results are discussed in Appendix C of the 2006 RA (SENES 2006). The arsenic concentrations in Baker Creek varied from about 100 mg/kg dw to 7000 mg/kg dw and the arsenic concentrations varied substantially from location to location. There were two samples upstream of Baker Lake, one location in Baker Lake, one location adjacent to the mill workings, one location downstream of the mill workings and two locations at the outlet of Baker Creek to Back Bay. The highest arsenic concentration in sediments was observed at the location opposite the mill site and the lowest concentration was measured at a located upstream of Baker Lake.

The sequential extraction tests indicated that 5% to 66% of the arsenic was potentially available. Likewise, the results of the bioaccessibility tests indicated that 4% to 33% of the arsenic was bioaccessible with a mean of 17%. A triangular distribution was applied to the bioaccessibility results and used to determine the risks to terrestrial species. A sensitivity analysis was also carried out for a bioaccessibility of 73% which represents an upper limit of bioaccessibility from literature studies.

For the muskrat, the mean intake is approximately 3.9 mg/(kg d) (see Figure 6.2-5e, f, g, and h in the 2006 RA document). The mean predicted intake using a bioaccessibility of 73% from the sensitivity analysis is 5.1 mg/(kg d) which is about 31% higher than the mean value reported in Figure 6.2-5. Comparison of the predicted mean value to the TRVs presented in Table 6 indicates that the results of the risk assessment would remain unchanged. In other words, the predicted intakes in both cases are above the LOAEL TRV used in the 2006 RA (SENES 2006) but below the LOAEL TRV based on the 2005 EcoSSL document.

In 2005, Jacques Whitford also collected samples in Baker Creek and conducted bioaccessibility tests. They determined that the bioaccessibility of arsenic differed with sample location which is similar to the results that were determined in 2004. The highest bioaccessibility results were obtained in Baker Creek Pond which was not sampled in the 2004 program. The range of bioaccessibility was between 14% to 96% with a mean of 56%. These values are higher than the values obtained in 2004; however, the mean bioaccessibility of 56% is lower than the bioaccessibility of 73% which is discussed above. The bioaccessibility results from the 2005 Jacques Whitford study were pooled with the bioaccessibility results that were used in the 2006 RA (SENES 2006) since the methodologies for assessing the bioaccessibility was the same. The pooled data indicates that a log-normal distribution with a geometric mean of 24% and a range from 4% to 100% best represents the information. Figure 2 presents a comparison of the muskrat intakes using the bioaccessibility data from the original 2006 RA and the intakes estimated using the pooled data.

Figure 2 Comparison of Muskrat Intakes for Different Bioaccessibility Studies



As seen from figure, the mean intake for the muskrat is higher using the pooled bioaccessibility data. The figure also shows a comparison of the intakes of the muskrat to the TRV derived from the 2005

EcoSSL data. As seen from the table, the intakes including the 95th percentile intakes are all below the LOAEL TRV. These results coupled with the findings of the biological surveys on muskrat indicate that there will be no adverse effects on muskrat and thus the results of the 2006 RA (SENES 2006) related to muskrat remain unchanged.

2. EEM Studies

The overall conclusions of the 2006 RA indicated potential effects to aquatic species in Baker Creek including predator and forage fish; however, environmental effects monitoring (EEM) studies carried out in Baker Creek by Golder in 2005 found an abundance of small-bodied fish such as spottail shiners and ninespine stickleback in Baker Creek. Young of the year for spottail shiners were found to be present in Baker Creek which suggests that the creek is suitable nursery and rearing habitat for this species. In 2008, the EEM survey noted improvements in water quality which allowed fish such as slimy sculpin to be found in Baker Creek. The EEM study also indicated that sub-lethal toxicity to aquatic organisms exists in Baker Creek. In summary, the results of the EEM studies indicate that the 2006 RA (SENES 2006) results may over-predict potential risks in the aquatic environment.

3. Summary

The above discussion indicates that the additional data and information that has become available since the 2006 risk assessment do not result in any changes to the conclusions of the risk assessment. In fact, the available information indicates that the risk assessment most likely over-estimates the risks associated with the remediation plan and thus represents a cautious estimate of the risks.

References

Andrade, CF. 2006 . *Arsenic Cycling and Speciation In Mining-Impacted Sediments of Sediment and Pore-Waters of Yellowknife Bay, Great Slave Lake, NWT.* Thesis, Master of Science, Queens University, Kingston, Ontario.

De Rosemond, S., K. Liber and Q. Xie. 2004. *Arsenic Concentrations and Speciation in Fishes from Back Bay near Yellowknife, NT.* Prepared for Department of Indian Affairs and Northern Development. August.

Dillon Consulting Limited 2002. *Biological Sampling at Baker Creek 2002.* Prepared for Indian and Northern Affairs Canada. November.

Golder Associates Limited. 2008. *Indian and Northern Affairs Canada Giant Mine Environmental*

Effects Monitoring Phase 2 Final Interpretative Report. Submitted to Environment Canada. June.

Golder Associates Limited. 2005. Miramar *Giant Mine Environmental Effects Monitoring Cycle1 Final Interpretative Report.* Submitted to Environment Canada. June.

Health Canada 2009. *Federal Contaminated Site Risk Assessment in Canada. Part II: Health Canada Toxicological Reference Values (TRVs). Version 2.0.* January.

Health Canada 2004. *Arsenic in Drinking Water. Document for Public Comment.* Prepared by the Federal-Provincial-Territorial Committee on Drinking Water. November.

HydoQual Laboratories (1989). *Water Quality Study of Yellowknife Bay 1987-1988.* Water Resources Division, Department of Indian and Northern Affairs.

Jackson, F.J., C.N. Lafontaine and J. Klaverkamp 1996. *Yellowknife – Back Bay Study on Metal and Trace Element Contamination of Water, Sediment and Fish.* Department of Indian and Northern Affairs Canada. November.

Jacques Whitford 2005. *Sediment Investigation of Baker Creek, Giant Mine, Yellowknife, NT.* Prepared for Giant Mine Remediation Project. December.

Koch, I., J.V. Mace, and K.J. Reimer 2005. *Arsenic Speciation in Terrestrial Birds from Yellowknife, Northwest Territories, Canada: The Unexpected Finding of Arsenobetaine.* Env. Tox.Chem. 24(6), 1468-1474.

Morales, K.H., Ryan, L., Kuo, T.L., Wu, M.M., and Chen, C.J. 2000. *Risk of Internal Cancers from Arsenic in Drinking Water.* Environ. Health Perspect., 108: 655-661.

Mudroch, A., Joshi, S.R., Sutherland, D., Mudroch, P., Dickson, K.M., 1989. *Geochemistry of Sediments in the Back Bay and Yellowknife Bay of Great Slave Lake.* Environmental Geology and Water Science, 14: pp. 35-42.

SENES Consultants Limited (2006). *Risk Tier 2 Risk Assessment Giant Mine Remediation Plan.* January.

U.S. EPA (U.S. Environmental Protection Agency). 2005. *Ecological Soil Screening Levels for Arsenic* – Interim Final. March.